Dust storms.—In the Middle West, about the middle of the period in question, dust storms were reported from many stations, and by noting the dates upon which dust was observed a fair idea of its progress can be obtained. The Signal Corps meteorological station at Fort Sill, Okla., reports that on the morning of the 12th, with a surface wind of 5.4 meters per second from the southeast and a wind of 17.9 meters per second from the southwest at an altitude of 700 meters above the station, the dust began to fill the air. The barometer was falling rapidly. This condition continued until about 2:30 p. m., at which time the air was filled with dust and the the sky was obscured. The moon that night was seen through a very heavy layer of dust. The station at Kelly Field (San Antonio), Tex., reported: "A severe wind and dust storm approached this field from the west about 3:15 p. m. The extreme velocity measured at this station on the surface was 13.4 meters per second at 3:20 p. m. No rain fell in the immediate vicinity, although it was observed raining 3 or 4 miles to the northwest at 3:07 p. m." Other stations reporting the phenomenon were Gerstner Field (Lake Charles), La., and Payne Field (West Point), Miss. The report from the former station on the 13th says: "A light haze became visible about 7 a. m. It was rather high, but gradually became lower and thickened. By 11 a. m. it had reached the surface. About 2 p. m. it became heavy and the dust particles were larger. They began to settle on objects where the air was quiet, and they irritated the nasal passages. About 4 p. m. the wind changed from WSW., where it had been most of the morning and early afternoon, to W. and WNW. The haze was dissipated rapidly and had disappeared by 4:30 p. m. At night a large diffused light area around the moon showed the presence of an unusual amount of dust in the air." The latter station, Payne Field, noted a "dry fog" or haze on the 13th. The sun was visible through it, but it is described as "silver white."

At various stations in Iowa and Illinois the dust was observed. At Alexander, Ill., the dust was accompanied by rain, causing the precipitation of what was described as "red mud." This occurred on the morning of the 13th. At Des Moines and at St. Charles, Iowa, samples of the dust were collected and were subjected to examination by Jacques W. Redway, of Mount Vernon, N. Y. Concerning the Des Moines specimen he says:

> * * * The essential part of the content consists of rounded grains of white quartz sand, and reddish, jaspery quartz sand. A few particles of crystalline fragments resembling calcite are in evidence. * * * It is difficult to account for the spherules of iron. They were not noticeable at first, but the pole of a magnet collected a considerable number of them. Meteoric iron has not been much in evidence in atmospheric dust since 1914; moreover, the spherules in the Des Moines specimen are materially different from any hitherto collected at this laboratory. In color and appearance they much resemble emery-wheel dust. Similar spherules are sometimes blown out of smelter stacks when a strong blast is employed. According to Mr. Reed (Weather Bureau official at Des Moines), there are no smelters in the vicinity of Des Moines. Mr. Reed also noticed that some of the dust clung to the ironwork of his instrument supports.

A later letter from Mr. Reed stated that while there are no smelters in that vicinity there are several small foundries, one of which is four or five blocks southwest of the station. It is possible that the iron particles may have come from that source.

It seems probable that this dust may have been picked up by the high winds in the southwest, carried eastward and spread through the atmosphere in the rear and southern portions of the storm.[5]

CONCLUSION.

This study again brings to our attention the absolute necessity for aerological data. One can not be content to study weather without a knowledge of what is going on in the third dimension. This paper has pointed out how current aerological data can be put to good use in forecasting precipitation; but the greatest good can not be realized until there exists an adequate number of aerological stations in the United States. These upper-air data are indispensable and the establishment of more stations is certain to lead to an ever increasing return upon the investment.

[5] Winchell, A. N., and Miller, E. R.: The dustfalls of March, 1918. MONTHLY WEATHER REVIEW, November, 1918, 46:502-506.

ECONOMIC RESULTS OF DEFICIENT PRECIPITATION IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau, San Francisco, Calif., October, 1920.]

SYNOPSIS.

Because of markedly deficient precipitation in northern and central California during the past four rainy seasons serious loss resulted during the dry season of 1920. Streams reached the lowest stages on record. The Sacramento River at Sacramento fell below mean sea level, and the current of the stream was reversed in direction. The saline waters of San Francisco Bay encroached upon rich agricultural lands of the delta region, reducing the vegetable crops, drove the dairy industry to other regions, and threatened irreparable damage to alluvial soils through the infiltration of salt water through seepage. For domestic use fresh water had to be transported on barges across the bay. The teredo, or "ship worm," a minute salt-water organism, did great damage to wooden structures. In the interior valleys the water problem has passed from one of too much water to one of too little. The average yield per acre of many crops was reduced in 1920 because of deficient moisture. Rice growers felt the drought keenly, because of the large water requirements of rice. Litigation over water rights has ensued, and additional legislation is apparently needed to meet new conditions. Hydroelectric power shortage resulted in power restrictions and higher rates for electricity, thus raising the cost of living. Wells went dry because of the lowered level of ground water. Forest fires were more frequent and destructive than in past years, owing to the parched condition of the forests. Partial relief from the drought came as a result of copious showers in October, 1920. The storage and utilization of fresh water is one of the most important problems confronting California to-day.

INTRODUCTION.

Comparatively few people residing in the central and eastern portions of the United States appreciate the value of the generous precipitation received in those regions. In the West and Southwest, and particularly in California, water is wealth, and irrigation water is aptly termed "the lifeblood of the State." Since successful agriculture requires a minimum of 15 to 20 inches of water a year, vast regions in the West, where the annual precipitation is normally below those amounts, are largely dependent upon artificial irrigation. Most of these irrigation systems receive their supplies from the relatively heavy precipitation of the mountain regions, and the water is conducted through artificial canals from streams or from natural or artificial reservoirs. In designing such systems due allowance is made for abnormally heavy or deficient precipitation. But when abnormally light precipitation recurs for three or four consecutive years the inevitable water shortage brings economic results which cause a community to recognize the necessity of an adequate water supply.

Northern and central California have received deficient precipitation during the past four rainy seasons. Disaster seemed to threaten when the season 1919–20 started out to be the driest on record. In February, 1920, the public utility commission of the State of California organized a "water-conservation conference," composed of the various national and State agencies concerned with the water problem.[1] At meetings of the conference the problem was discussed in detail, the public was warned of the impending shortage, and every effort was made to conserve water. Fortunately March and April brought abundant precipitation, but an insufficient amount to make up the deficit. Mr. Paul Bailey, civil engineer, was appointed watermaster by the conference, and he went immediately to the Sacramento Valley to urge water conservation. He remained there the greater part of the summer, carrying out measures tending toward an equable distribution of the limited water available. As the growing period of the season of 1920 is now over, and the early autumn rains of the season of 1920–21 have begun, it is believed that a brief résumé of the results of the deficient precipitation will be of interest from a scientific and an economic standpoint, as well as from the viewpoint of the engineer.

STREAMS REACH RECORD LOW STAGES.

During the summer of 1920 nearly all streams in northern and central California reached the lowest stages on record, and some of the smaller streams dried up entirely. At Rio Vista, on the Sacramento River, and 70 miles inland from the Golden Gate, the river fell to a point more than a foot below mean sea level on August 24, and remained at about that stage for five consecutive days. At Sacramento, 90 miles inland from the Golden Gate, the Sacramento River on August 2 fell to a point 0.5 foot below mean sea level, the lowest stage on record.

Physiographically San Francisco Bay is a drowned or submerged valley, being the lower reaches of the Sacramento-San Joaquin River. The region has been submerged during geologically recent times, and there is evidence that the subsidence is still in progress. The water of the bay is saline, and under normal conditions the water of the two large streams which flow into it is fresh. But because of the low stages of these streams during the summer of 1920 the flow in the lower portions was actually reversed at times, and the salt water flowed inland, encroaching upon rich agricultural lands which in the past had been irrigated by seepage and the pumping of fresh water from the natural flow of these streams. For many years this favored delta region has been termed "San Francisco's bread basket," for every year there were grown in this region 20,000 carloads of potatoes, celery, tomatoes, asparagus, and various deciduous fruits. Moreover, it is a rich dairy region, as the summer fogs keep the pastures green throughout the summer. While in past years flood was the single source of fear, in 1920 the curse of salt water markedly reduced the crops, and threatened irreparable harm through the infiltration of salt in the rich alluvium. The acreage of vegetable crops was reduced in anticipation of the water shortage. Dairymen moved their cattle to more attractive regions.

As the summer progressed the saline water moved farther and farther up the river. At the sugar refinery of the California-Hawaiian Sugar and Refining Co., at Crockett, where 400,000 tons of cane sugar are manufactured annually, it was found necessary to transport fresh water by barge across the bay in order to continue operations. Subsequently the saline water reached Antioch, still farther inland, and pipes and boilers in homes and factories were eroded and later fell to pieces. At a $2,500,000 paper-board mill situated near Antioch, and which required 1,500,000 gallons of fresh water per day for operation, barges for carrying fresh water were also put into use to prevent a complete shutdown. It cost the town of Antioch $15,000 a month for domestic water supply. Residents were placed on a water ration of five gallons per day per family.

THE "SHIP WORM" ACTIVE.

The encroachment of saline water into regions previously unaffected introduced a destructive force of great economic consequence. This is the teredo, a minute, marine organism, popularly known as the "ship worm," which survives only in water having a salt content between 0.5 and 4 per cent. (Water in the North Pacific Ocean is 3 to 4 per cent salt.) This organism burrows into wood which is in contact with the salt water in which it lives, and eventually the "honeycombed" wood structure is so weakened that it collapses. The spread of the teredo through the encroachment of the saline water of San Francisco Bay did great damage to wooden structures. On September 25, 1920, a wooden wharf at Port Costa, 1,000 feet long and valued at $5,000, collapsed as a result of teredo operations, and there were precipitated into the bay $10,000 bags of freshly harvested barley, valued at $25,000. Other wharves in the vicinity were subsequently abandoned. The Southern Pacific ferry, which transports railroad trains across the stream at this point, had to be dry-docked, and the wooden bottom was replaced with a new copper-covered bottom.

It is conservatively estimated that the teredo did damage exceeding $1,000,000 in amount in the San Francisco Bay region during the summer of 1920. In order to prevent further loss, property owners on the water front subscribed $25,000 to secure the services of experts to study the problem and to recommend measures of combating further depredations of this organism. Representatives of the Forest Products Laboratory, of Madison, Wis.; of the University of California, of Berkeley, and of the Wood Preservation Association, of San Francisco, are at present engaged in this research.

DROUGHT EFFECT IN THE INTERIOR VALLEYS.

Outside the bay and delta regions the economic losses resulting from the deficient precipitation were not less apparent. The Sacramento-San Joaquin Valley is a fertile region, the seat of northern California's agriculture, the crops consisting principally of grain, alfalfa, and fruit. The San Joaquin Valley has become the richest raisin and grape producing region in North America. During recent years the flood plain of the Sacramento Valley has become a valuable rice-growing district.

For more than a quarter of a century agricultural, irrigation, engineering, and political leaders have urged that some comprehensive scheme be carried out to get the maximum use of the Sacramento Valley's water and to minimize damages done by it. The flood menace compelled first attention. In 1894 C. E. Grunsky and Marsden Manson urged flood control by: (1) Rectification of channels; (2) overflow weirs at certain points; and (3) leveed by-passes to carry the overflow. This proposition has been carried out to a large extent by the State reclamation board. However, this plan had no

[1] See MONTHLY WEATHER REVIEW, March, 1920, 48: 156–157.

relation to irrigation or power; and the problem has lately passed from one of too much water to one of too little.

The scope and nature of the work which may be done to increase the low-water flow was recently indicated by Fred H. Tibbetts, representing the Association of Northern California Irrigation Districts, who advocated: (1) Diversion into the Sacramento River of water from other watersheds, such as the Klamath River; (2) storage of flood waters now running to waste during winter and spring; (3) prevention of advance of salt water from the bay, thus rendering usable the flow now necessary to insure fresh water in the delta; (4) canalization of the Sacramento River by a system of locks to decrease the flow necessary for navigation.

In February, 1920, Prof. Frank Adams, of the United States Department of Agriculture and the University of California, proposed at a meeting of the Sacramento Valley Department Association that the entire valley be organized by the State legislature into a single State conservation and flood-control district, merging flood control, reclamation, drainage, and irrigation into a single, unified projects.

In harmony with that suggestion, there was launched in September, 1920, a project, the engineering features of which were designed by R. B. Marshall, of the United States Geological Survey, whereby through the construction of one gigantic storage and irrigation project there would be reclaimed an additional 12,000,000 acres of land. The Marshall plan proposes the storage of enough water in the Sierra Nevada Mountains to fill reservoirs sufficient to reclaim all the irrigable lands in the Sacramento, San Joaquin, and other adjacent valleys, and the distribution of these waters through a system of canals. It is estimated that the project would cost between $600,000,000 and $700,000,000 and would add billions of dollars to the wealth of the State. As an indication of the certain success of the project, it is pointed out that the crops from the Roosevelt project in Arizona during 1919 alone were of value twice greater than the entire initial cost of the engineering works connected therewith. California can support a population of 30,000,000 people with the proper storing and distribution of water.

Because of generous rains during March and April, 1920, the agricultural interests of northern California did not experience the disaster which threatened earlier. However, the yield per acre of nearly all crops was below normal. In the San Joaquin Valley the raisin crop was 20,000 tons less than that of 1919. The hay crop was everywhere short, pastures dried up earlier than usual, and in regions where alfalfa is grown without irrigation the water table dropped so low that the crop was markedly deficient in quantity and in quality. As orchards were given preference in the distribution of irrigation water, the fruit crop was large. In fact, because of increased acreage of bearing orchards the shipments in 1920 were larger than those of 1919. Up to October 12 a total of 26,504 carloads of deciduous fruit were shipped from the State, compared with 23,249 carloads during the same period in the previous year.

WATER SHORTAGE AND RICE GROWING.

From an agricultural viewpoint, the rice growers were affected more by the water shortage than any other single group. Rice growing is a new industry in California, the first experiments on a commercial scale having been inaugurated in 1914. The rich alluvial flood plain of the Sacramento River has been found to be well adapted for rice growing, and the weather of the region is ideal. The growing of rice has been the means of transforming worthless swamp land into land worth several hundreds of dollars per acre. The rice crop of 1920 is valued at $62,000,000.

The old crops of the Sacramento Valley—grain, alfalfa, and fruit—use each season about 18 inches of water, enough to cover the soil to that depth is all applied at once. Rice, on the other hand, requires 60 to 120 inches of water instead of 18 inches. Moreover, it is estimated that 40 inches of water evaporate off of a rice field during the hot, dry summer. The fields are flooded artificially during the growing season and drained just before harvest. Abundant water is needed each summer until about September 15.

In anticipation of the impending water shortage the rice growers voluntarily reduced by 50,000 acres the area devoted to rice in 1920 as compared with that used in 1919. The watermaster appointed by the conference devoted practically all of his efforts to conserve and to reduce the water demands of the rice growers. President William Durbrow, of the Glen-Colusa Irrigation District, stated in the Pacific Rural Press of August 28, 1920, that "the Sacramento River has been practically pumped dry."

The landowners in the delta region and the commercial interests of the San Francisco Bay region united forces in the spring of 1920 and sought an injunction in the courts of law for the purpose of restraining the rice growers of the Sacramento Valley from taking water from the Sacramento River. They reasoned that the damages they had sustained and were about to sustain were due to the encroachment of saline water of the bay because of the decreased flow of fresh water of the Sacramento River, and that this diminished flow was due to the excessive pumping of water for rice irrigation upstream. The rice growers contended that the decreased flow was the natural result of the deficient precipitation of the past four rainy seasons, which had depleted the mountain reservoirs and lowered the ground water level to abnormally low stands. Suit was brought in the name of the town of Antioch, which contends that its domestic water supply is ruined. The case involved $62,000,000, the value of the rice crop, the largest amount ever involved in litigation in the State of California.

As is usual in law cases, the suit filed last spring has been long delayed in settlement, and the case is still before the courts, though the rice crop is now being harvested. However, much depends upon the outcome of the case, as it is believed that this is a forerunner of a more important suit which will take years to decide and which will involve many questions. It is sufficient to say that the problem of water rights is a complex one in California. Unfortunately, the law is not clear, and riparian and priority rights are so involved that a layman can not comprehend them. It appears that additional legislation will be needed to clear up many doubtful points at issue.

MISCELLANEOUS RESULTS OF WATER SHORTAGE.

Hydroelectricity is the principal source of mechanical power in California. The natural flow of streams is the ultimate source of power in the winter and spring months and water from storage reservoirs turns the wheels in the summer. Supplementary steam plants burning fuel oil are used in the autumn and at other times when hydroelectricity is unavailable.

Because the natural flow of streams was abnormally low and the stored water was deficient, resort to steam plants for generating electricity throughout central and northern California was general during 1920. Because of the high price of fuel oil, and the increased cost of transportation and higher labor charges, the public utility commission granted the power companies permission to raise rates on electricity 15 per cent. This served as an excuse for higher rents, and all residents thus felt another increase in the cost of living, indirectly due to the deficient precipitation of last winter. The street car companies, the largest single users of electricity, adopted the skip-stop system to reduce consumption of energy, and also took off many cars to reduce the demand for power. Through moral suasion and a simple presentation of the facts, the utility commission's power administrator succeeded in eliminating all electric advertising signs on five nights of the week, and the unnecessary lighting of store windows and streets was reduced. In the mountain regions many mines using electric power were compelled to shut down. Gold dredgers using electricity ceased to operate.

In the Santa Clara Valley the well situation became serious in midsummer, owing to the depletion of underground waters. Emergency measures were adopted to preserve the levels of these underground waters so that the overlying orchards could be saved.

At the United States Immigration Station on Angel Island, in San Francisco Bay, the only well on the island went dry in midsummer, and fresh water had to be transported by barge from Marin County.

Due to the deficient precipitation of the past four rainy seasons, the forests in the elevated regions of California became very dry and suffered severe injury from fire during the summer. August, 1920, was perhaps the most disastrous month for forest fires which the State has thus far experienced. The situation became so serious that billboard posters were displayed by the United States Forest Service, informing citizens of the situation and cautioning those going to the forests for recreation to be particularly careful in the use of fire. Experienced fire-fighters were transported by aeroplane to the larger conflagrations. Lightning was a prolific source of fires in the parched forests throughout the long dry summer. The "back fire" from an automobile truck passing near Paradise, Butte County, set fire to a dry pasture, and 15,000 acres were burned over before the fire was controlled.

Relief came as a result of copious showers and cool weather in October. Fruit trees were revived, the forest-fire hazard was reduced, and the hydroelectric situation was relieved to such an extent that all power restrictions were immediately removed. Thus ended a season in which more attention was paid to rainfall statistics than ever before in the history of California. It is no exaggeration to say that for the past year the official rainfall data have occupied a place in public interest on a par with vital statistics, bank clearings, stock quotations, and market reports.

In commenting on the situation, the San Francisco Chronicle in an editorial on August 13 stated:

> Rain or shine, for the next decade the most important matter before our people will be the storage, so far as humanly possible, of every drop of water which falls on the State, and its utilization for irrigation and the development of power.

THE RELATION OF PROLONGED TROPICAL DROUGHTS TO SUN SPOTS.

By Prof. W. H. PICKERING.

[Mandeville, Jamaica, July 2, 1920.]

SYNOPSIS.

A study of the collected rainfall data covering the last 50 years in the island of Jamaica has shown that there have been 12 droughts, 9 of which have followed closely after a sun-spot maximum or minimum. It appears that droughts occurring after the maxima show a greater deficiency of rainfall, and last longer, than those occurring after the minima. On the basis of sun-spot data a drought, predicted in March, 1919, to begin during 1919 or 1920, actually began in June, 1919, and was continuing at the time of writing the paper. It is suggested that the cause of the variations of rainfall may lie in the effect of changes in ocean temperatures on condensation and evaporation in the Tropics, and the increased solar magnetic activity after sun-spot maxima, although the reason for such a solar relation is not apparent. The effects of volcanic dust on radiation may also be a factor.—*C. L. M.*

The island of Jamaica is situated south of Cuba, in latitude 18° N. Its area is 4,200 square miles, or a trifle less than that of the State of Connecticut. The whole island is mountainous, culminating in the east in Blue Mountain Peak, 7,360 feet in height, but in the greater part of the island the elevations do not exceed 2,000 to 3,000 feet. At the suggestion and under the superintendence of the late Maxwell Hall, the Government, in 1870, began publishing the rainfall data for the island, and the fiftieth year has just been completed.

The rain is collected in gauges 5 inches in diameter with their tops elevated 1 foot above the ground. The observers are Government officials, planters, and cattlemen. In 1870 there were 24 stations, one of them dating back to 1862. Less than a dozen of these original stations are still maintained, others taking their place. On January 1, 1920, there were 196 stations, or one for every 22 square miles of territory, scattered as uniformly as practicable over the island. At no station here considered have the observations been continued for less than 10 years.

The rainfall is very unequal in different portions of the island. Thus at Moore Town near the entrance of a funnel-shaped valley at the extreme eastern end of the island, altitude 600 feet, where the trade winds impinge on the high mountains, the annual rainfall is 248 inches. On Blue Mountain Peak itself it is 175. On the other hand, at Bull Bay, 8 miles east of Kingston, and 20 miles from Moore Town, but on the other side of the mountains, it is only 33. The island has therefore been divided into four nearly equal sections according to their topographic features, and in Table 1 the rainfall is given for each of these sections and also for the island as a whole by decades. The mean rainfall for the island for the 50 years is 72.86 inches. It will be at once noticed that the means for the first two decades of this rainfall are very similar, and also the means for the last three, but that the two results differ from one another by about 10 inches. By examining the deviations from the mean, we see that the increased precipitation of recent decades is recorded mainly in the two rainiest sections of the island, the northeastern and west central, but that the other sections also show an appreciable increase. There does not seem to be any evidence that the change is due to the abandonment of certain stations and the establishment of others, but rather to an actual increase in the rainfall over the whole island.

In Table 2, in the second column, is given the mean annual rainfall for successive years, and in the third these results are smoothed by the well-known device of taking the mean of the first five results from the second column and entering it on the third line. The mean of the second, third, fourth, fifth, and sixth results is entered on the fourth line, and so on. These results are plotted in